MICRODYNAMICS PROGRAM OVERVIEW:

Qualify & Quantify

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What Are Microdynamics?

- Defined as sub-micron nonlinear dynamics of materials, mechanisms (latches, joints, ...) and other interface discontinuities

- Linked to the quasi-static hysteric behavior of local mechanisms

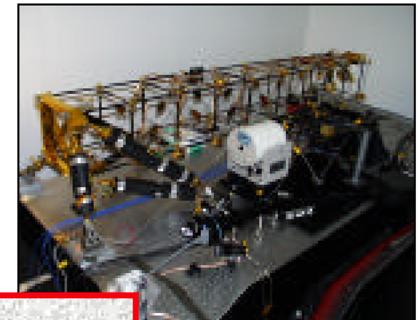
  Causes nonlinear dynamic response within the global structural system

- Can create dynamic disturbances induced by slip from both transient and quasi-static loads (e.g., thermal strains, mechanism motion …)

  Exhibited as "Microlurches", "Snaps" and other transient responses in the instrument which affect stability

Microdynamics includes the study of both the nonlinear mechanical response, as well as its effect as a broadband non-stationary disturbance source

Bringing Together New Technology for a Common Goal



Flight Validation

μdynamic Modeling & Analysis

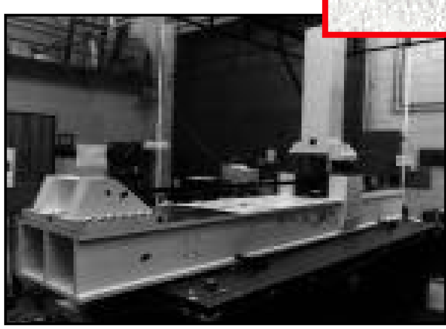
Project Implemen-tation

REDUCING RISK & IMPROVING DESIGNS

Component & System Tests

Gravity Effects

Thermal & Cryogenic Effects



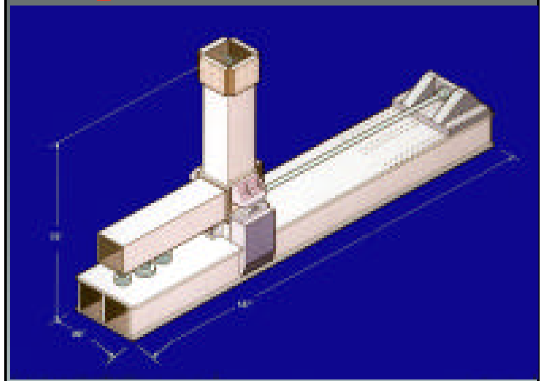
Nanostrain Damping & Transmission

H/W Design

The e-Team

INDUSTRY

Raytheon



- *Axial damping.*
- *Damping in the presence of DC preloads.*
- *Micronoise transmission*
- *Analytical friction models*
- *Components & structures*
- *Mechanical H/W design*

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Mechanical H/W design

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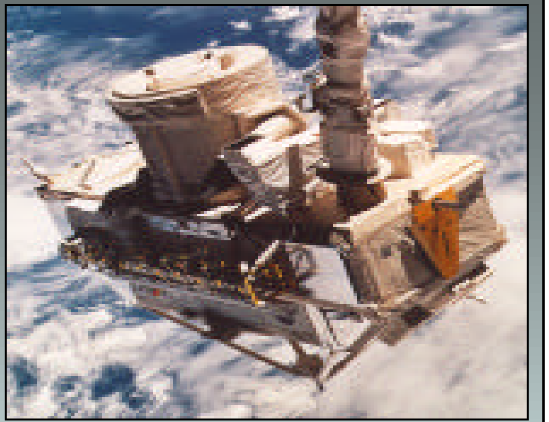
SIM design and verification

GOVERNMENT

JPL



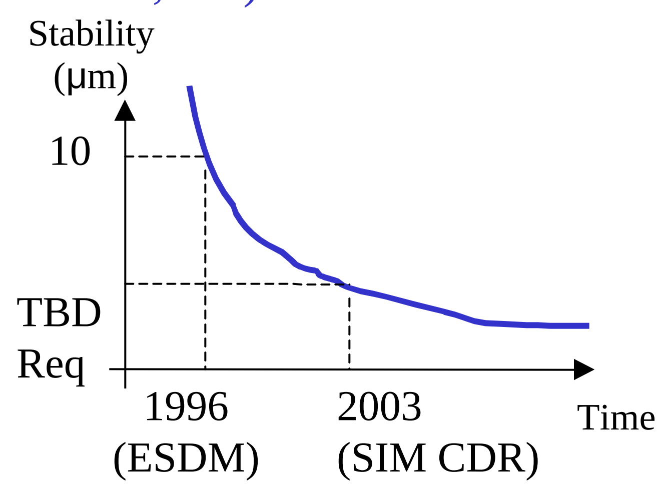
- *Flight experiments*
- *Data analysis & visualization*
- *Ground test verification*
- *Project implementation & verification*

•LaRC
Deployment H/W design & test
Microdynamic Design Guide

ACADEMIA

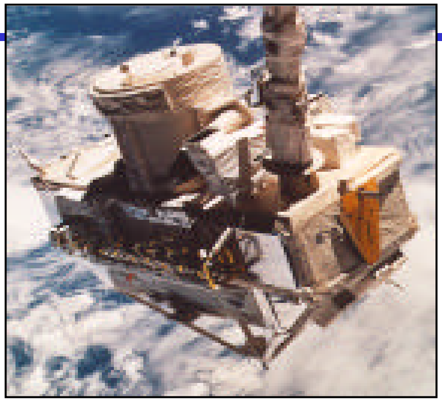
We've Come a Long Way Since 1996:

- Flown 2 Missions (IPEX-I & II)
- Demonstrated that Microdynamics exist (IPEX, HST, MIT, CU, Raytheon, LaRC)
- Analyzed flight data to quantify nonlinearity and dynamic disturbance
- Developed analytical models of slip and friction (CU, Raytheon)
- Proposed Load Path Management approach (Hachkowski, CU)
- Used analytical models to design optimal mechanisms (LaRC, CU, Foster-Miller)
- Developing rigorous testing techniques & methodologies to characterize microdynamics (CU, Raytheon)
- Published over 25 reports & papers

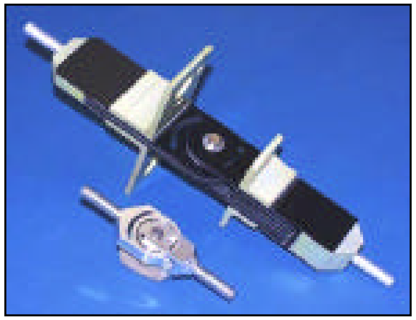


We have demonstrated that microdynamics exist.
The next step is to qualify and quantify microdynamics through rigorous testing and analysis techniques

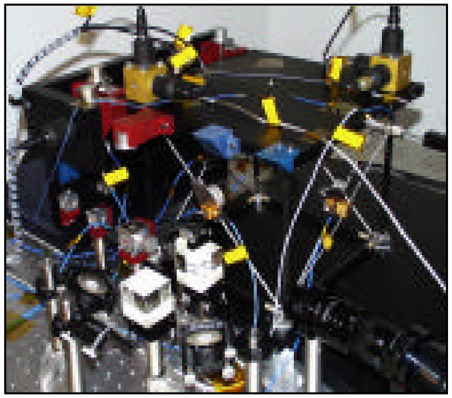
Work In Progress: Qualify & Quantify



- **IPEX-II**
  - Flight Data Analysis (M. Ingham)
  - Ground Modal Tests (G. Ortiz)
  - Microdynamic Tests (L. Hardaway)



- **Contact Mechanics & Microdynamics**
  - Damping & Testing (R. Hachkowski)
  - Analysis (L. Peterson)
  - Design Guide (M. Lake)
  - H/W Design (P. Warren)
  - SIM Implementation (N. Kashkari)
  - Cryogenics (J. Hinkle)



Future Directions for the μD Effort: From Quantification to Project Implementation

- **More of the same ... Generic Microdynamic Technology Development**
  - Link component level μD to system level μD (test & models)
  - Link hysteresis to dynamic/quasi-static disturbances
  - Increase focus on secondary load paths elements (e.g., cables, MLI, ...)
  - Assess disturbance propagation effects
  - Assess zero-g effects
  - Test project critical h/w as it becomes available

- **Integration of the μD technology into the Project**
  - Best design practices
  - Project implementation and verification plan
  - Requirements flowdown from optics to mechanisms
  - Risk reduction and mitigation (e.g., load path management, damping strategies, operational sequences, ...)

Microdynamics Mitigation is Linked to Load Path Management & Contact Mechanics

- Contact mechanics is a well understood and documented field
  (Ref:, Hertz-1882, Johnson- 1985)

- The current challenge is to verify applicability at nanostrain levels and translate mathematical theories into engineering concepts

- The main parameters affecting microdynamics are:
  - topology of the contact area
    - Non-Conforming (point contact)
    - (line contact)
    - Conforming (surface contact)

    •Stress controlled by geometry and load

    •Stress determined by manufacture tolerance
  - stress distribution across the contact area and friction direction
    - normal loads
    - shear loads

Microdynamics Mitigation Must Consider the Topology of the Mechanisms as well as the Primary/Secondary Load Paths of the Overall Structural System

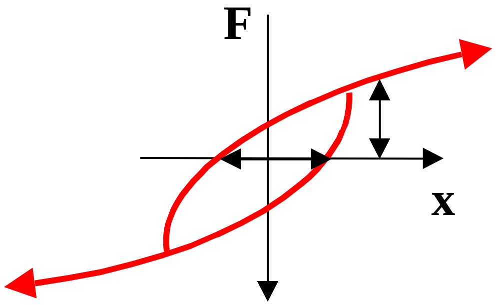
"Good Design Practices" are Based on the Physics of Contact Mechanics

- The primary objective is to reduce microslip and hysteresis as to make the components:
  - **more predictable**
    - position accuracy and stability
    - model-based representation
  - **more linear**
    - force *uniquely* proportional to displacement
      - no hysteresis (load amplitude/rate dependent)
      - no creep (time dependent)
    - single frequency in = same frequency out
  - **minimize its effect as a disturbance source**
    - quasi-static
    - dynamic
    - multi-mode response

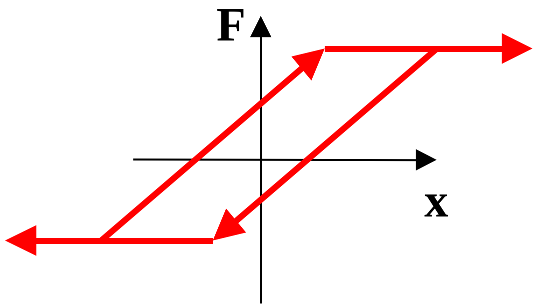
- Other objectives:
  - propose mitigation strategies to isolate/dampen/control/localize μD effects
  - devise load path management strategies for load transfer to critical components
  - investigate contribution of non-structural components (cables, MLI, ...)
  - recommend analysis approach for prediction

- The "Good Design Practices" handbook will **NOT** be an exhaustive list of what materials to use, friction coefficient design curves, etc...

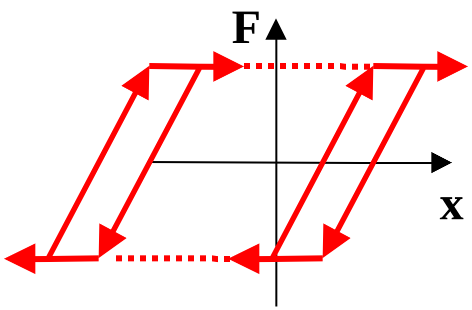
Types of μD Mechanics Form the Basis for Design Requirements and Specifications



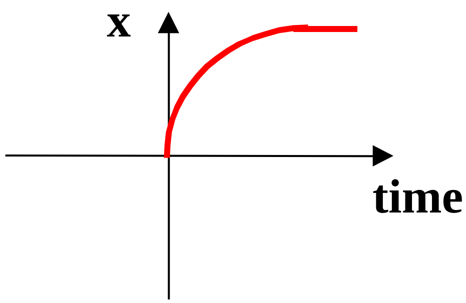
Hysteresis
- measure of the static position uncertainty
- measure of energy dissipation (friction & damping)



Smoothness
- measure of the state transition rate
- possibly related to harmonic distortion & dynamic snap disturbance



Stability
- measure of the state stability
- propensity for multiple equilibrium zones
- post-deployment microlurch



Creep
- mechanical response lag to constant load
- quasi-static time varying deformation
- visco-elastic materials, glue, bonding

Top Level Design Recommendations

- **Design an INTEGRATED system**
  - the mechanism should not be a separate entity or an after-thought
  - design a structural system with well defined load paths (e.g., it is easier to analyze the load path in a truss structure with flexural I/F, than in plate structures with bonded joints)
  - understand how/what the loads will be applied at the interface (thermal, mechanical, gravity, slews ...)

- **Make the interface contact as simple as possible**
  - single point contacts have less hysteresis, easier to model, less prone to slip
  - hysteresis, model complexity, machining tolerances and slip increase with surface dimension (1-D, 2-D)

- **Make the interface load normal to the friction path**
  - do not design the mechanism to carry load through friction
  - pre-load affects the character of the interface hysteresis

- **Perform analytical simulations**
  - global FEM models for interface load definition
  - component mechanism model for interface stress distribution
  - defines testing strategies for performance verification

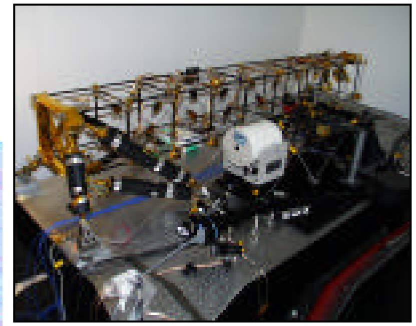
Goals of the Microdynamics Project Implementation and Verification Plan

- Understand and translate into engineering designs the mechanics of friction to
  - *formulate requirements for hysteresis, stability and disturbance generation*
  - *bound the quasi-static & dynamic disturbance source*
  - *specify test procedures for requirement verification*
  - *devise modeling tools for μD performance predictions*
  - *understand and bound the effect of gravity, and testing in 1-g environment.*
  - *recommend flight operations sequence to minimize μD (dithering, settling times,...)*

- Need to develop a process for formulating this plan:
  - *Must understand the flowdown of optical performance to microdynamic stability*
  - *Requires end-to-end opto-mechanical test-analysis validation (not a simple task)*
  - ***Cannot*** *apply frequency-based RMS requirement approach to quasi-static, transient, & non-stationary disturbances.*

- Issues:
  - *Existing dynamic test and verification plans are based on (30) years of experience*
  - *Microdynamics is a new concern, with very little flight heritage.*

Conclusion: Establishing a Framework for Project Implementation



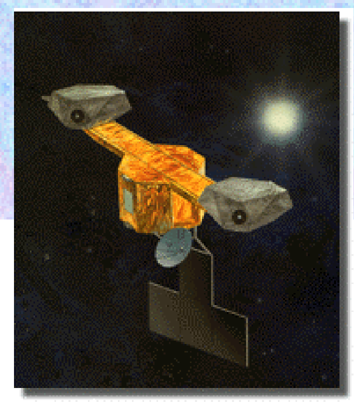
Proof of μD Existence

- **Testing Methodology**
- **Analysis Tools**
- **Experimental Data**
- **Design Approach**

Qualify & Quantify

- **Requirement Formulation**
- **Verification Plan**

SIM Classic



Son of SIM

μD Project Implementation